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Trace Elements Status and Strength of Compacted Arable Soils of Akure Nigeria

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Abstract

Trace elements in arable soils have become an environmental issue that it has to be investigated for sustainable agricultural production. Investigations were carried out in the laboratory to determine some physical, geochemical and mechanical properties of three profiles (A, B, and C) of arable soils. The properties investigated were shear strength, and trace elements status in the surface and subsurface horizons. Shear vane tester was used to measure soil shear strength and atomic absorption spectrophotometer was used to determine the trace elements status of the soils. The three profiles studied were predominantly clay loam in texture across the horizons except the profile B which was clay in the 30-40 cm depth layer. The specific gravity of the experimental soils ranged from 2.65 to 2.77. The plasticity index of the profiles A, B and C ranged from 8.6 to 10.7, 9.3 to 10.7 and 10.0 to 10.7, respectively. The soils were characterized by relatively low levels of identified trace elements. Results showed that 8.5 mg/kg of lead (Pb) was the highest value of trace elements, while 0.3 mg/kg of Iron (Fe) was the lowest value of the soil trace element observed. The most notable characteristics of the soils were the low organic matter content and the predominantly acidic pH. The bulk density of the sample varied between 1.72 and 1.86 g/cm^3. The range of the maximum shear strength of compacted soil was 150.75 to 156.14, 154.79 to 160.17 and 162.87 to 166.90 kPa for profiles A, B and C, respectively. The mean moisture content during the study varied from 14.5 to 18.9% (db). The data presented in this study is good for planning and soil management practice.

Key words: Soil properties; Trace elements; Shear strength; Moisture content; Soil profile

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INTRODUCTION

Trace elements are defined as those elements that are present in a rock at concentrations below 0.1% or 1000 mg·kg^{-1} (Rollinson, 1993). Soil is the main source of trace elements for plants both as micronutrients and pollutants. Some exceptions are in situations of heavy pollutants or from flooding by contaminated waters (Kabata-Pendias, 2004). All over the world today, environmental management has become an issue and a challenge that must be investigated thoroughly so that modern technology can be used to solve pollution problems. This assertion has prompted various reports from researchers (Yang *et al.*, 2008; Tan & Lau, 2010; Chang & Wu, 2011; Tang *et al.*, 2011).

The distribution and content of these chemical elements in soils depend on several factors: nature of the parent material, weathering processes and human activity (Martinez, *et al.*, 2003). Some of these elements are essential nutrients for plant growth as well as for human and animal health. However, at elevated levels some trace elements become potentially toxic, therefore acting as soil sinks for these compounds (McBride, 1994). Plants require water, air, light, suitable temperature, and 16 nutrients to grow. Plants absorb carbon, hydrogen and oxygen from air and water. The other 14 nutrients come from the growing medium/soil. Soil nutrients are divided into two groups according to their demanded quantity by the plants. The macronutrients are those that are demanded in relatively high levels (Ronen, 2007). The micronutrients, which are needed only in trace amounts, are iron (Fe), manganese (Mn), boron (B), zinc (Zn), copper (Cu), molybdenum (Mo), chloride (Cl), sodium (Na), nickel (Ni), silicon (Si), cobalt (Co) and selenium (Se).

Trace elements importance for plants differs since there are essential micronutrients heavy metals (Fe, Mn, Zn, Cu, Ni, Mo), and also beneficial (Co) or non beneficial toxic heavy metals (Cd, Cr, Pb, Hg) (Lončarić *et al.*, 2010). The concentration of heavy metals in soils is influenced by activities such as agricultural practices and industrial activities and is associated with biological and chemical cycles. It is also reported that the importance of micro-elements in plant nutrition is high and they should not be neglected although they are needed in minor quantities (Ronen, 2007). It was reported that the total contents of trace elements in solutions of uncontaminated mineral soils range from 1 to 100 μg/l, while in contaminated soils, the values can be much higher (Kabata-Pendias, 2004).

In Nigeria, published articles are scarce on studies of trace elements as regards occurrence, effects on ecosystem and remediation. This study therefore has the following objectives to: determine the status of trace elements in the arable soil of a project site; and also to assess the shear strength of the compacted soils.

Soil strength is one of the most dynamic soil mechanical properties, and its knowledge is important to tilth, plant growth, and soil biological activity. Soil strength when influenced by management and soil properties controls plant growth, root development, and soil-moisture relations. The impact of textural and structural parameters on soil strength is moderated by soil organic carbon (SOC) concentration (Blanco-Canqui *et al.*, 2005). High soil strength limits root growth and crop production (Busscher & Bauer, 2003), reduces hydraulic conductivity and infiltration, increases runoff and soil losses, and thus adversely affects environmental quality (Go´mez *et al.*, 1999).

Knowledge of shear strength dynamics is crucial to understanding the mechanical behaviour and structural sustainability of agricultural soils. Soil management changes the resistance of soil to shearing stresses (Blanco-Canqui *et al.*, 2005). Soil shear strength has been used, with varying degree of success, to predict soil resistance to erosion or erosion related processes. Shear strength measurements are based on the stress at soil failure, which is used for the calculation of the properties soil cohesion and angle of internal friction. Shear strength can be measured in direct shear, triaxial, and shear vane tests (Ohu *et al.*, 1986; Horn & Lebert, 1994).

MATERIALS AND METHODS

Experiment Site

Experimental soils were taken from a two-hectare STEP-B Project site at The Federal University of Technology, Akure, Nigeria ($7^0 15^1$N, $5^0 15^1$E) and elevation 210 m. Three locations (A, B, C) about 10 m apart were randomly selected and considered at the surface and sub surface layers. At each point, a small (rectangular) pit of 90 cm by 70 cm was dug to expose the soil profile and the different horizons investigated in four-depth namely: 0-10, 10-20, 20-30, and 30-40 cm. Soil samples were collected at these depths.

Particle Size Analysis

Soil texture was determined using the hydrometer method (Gee & Bauder, 1986). Soil pH was measured in H_2O and in 0.1 M KCl using a 1:2.5 soil/solution ratio. The method of Olsen *et al*. (1953) was used to estimate available P. The soil organic matter was quantified by the Walkley and Black wet oxidation method (Nelson & Sommers, 1982). Ex-changeable cations were determined using an ammonium acetate extraction method (Thomas, 1982). Exchangeable Na, K, Ca and Mg were determined by atomic absorption spectrometry. Total nitrogen content was determined by the Kjeldahl method (Bremner & Mulvaney, 1982).

Trace Elements

Extracts used for determining trace elements were obtained by leaching soil samples using 0.1N EDTA. The concentrations of extractable iron, manganese, copper and zinc were determined using an atomic absorption spectrophotometer (AAS), Bulk Scientific Model 210 VGP (Figure 1). Soil pH was measured potentiometrically in 0.01M calcium chloride solution using a soil to solution ratio of 1:2. Soil pH was measured because soil reaction influenced the availability of plant nutrients in the soil (Aweto & Oyegunwa, 2000).

Figure 1
Atomic Absorption Spectrophotometer (AAS) Bulk Scientific Model 210 VGP Used in the Study

Shear Strength Determination of Compacted Soil

To determine the shear strength of the soils, samples were sieved with 2 mm sieve in the laboratory. Three replicate soil samples in each case were compacted using the standard Proctor method as reported (Ekwue & Stone, 1995; Ohu *et al.*, 1986). Compaction was carried out at 25 blows of standard (2.5 kg) Proctor hammer at moisture contents between 14.2 and 17.2 % (db) in a cylindrical mould of 100 mm diameter and 120 mm height. The moisture contents were chosen according to the consistency limits of the soils. A round wooden disc pad was placed on the soil before compaction in order to ensure uniform compaction of the soil in the mould. Shear strength readings were taken at two depths (5 cm from top and bottom of the mould) with a 19 mm vane size shear vane tester (Hand vane tester, SL810, Impact Test Equipment Ltd., Stevenston Ayrshire KA20 3LR, UK). The shear vane tester was inserted into the soil at the stated depths and twisted uniformly until the readings of the pointer stopped increasing. This indicated soil failure and the shear readings obtained were averaged to compute the mean shear strength of the soil column.

RESULTS AND DISCUSSION

The result of particle size analysis is given in Table 1. The three profiles were predominantly clay loam in texture across the horizons except the profile B which has clay texture in the 30 to 40 cm layer. The specific gravity of the experimental soils ranged from 2.65 to 2.77. The main chemical characteristics of the profiles studied are given in Table 2. It was observed that organic matter content was low, ranging from 0.28 %-2.62 %. The organic matter content was only substantial in the 0-10 cm horizon and dropped significantly in the lower horizons. The observed values of organic matter content were probably mainly the result of the warm climate and tillage management of the land.

Table 1
Particle Size Distribution of Experimental Soil

	Soil depth	% sand	% clay	% silt	Textural class	Silt + Clay	Specific gravity
A	0-10	37	37	26	Clay Loam	63	2.65
	10-20	37	39	24	Clay Loam	63	2.65
	20-30	35	39	26	Clay Loam	65	2.68
	30-40	37	41	22	Clay	63	2.66
B	0-10	43	33	24	Clay Loam	57	2.67
	10-20	37	37	26	Clay Loam	63	2.67
	20-30	37	37	26	Clay Loam	63	2.74
	30-40	37	37	26	Clay Loam	63	2.74
C	0-10	43	33	24	Clay Loam	57	2.72
	10-20	39	37	24	Clay Loam	61	2.77
	20-30	43	33	24	Clay Loam	57	2.76
	30-40	42	33	25	Clay Loam	58	2.72

Table 2
Chemical Properties of Experimental Soils

Soil sample	Mean depth(cm)	Textural class	pH in water 1:2	Organic carbon (%)	Organic matter (%)	N (%)	P (mg/kg)	K^+	Na^+ cmol/kg	Ca^{2+}	Mg^{2+}
A 0-10	A 5	clay loam	6.34	1.48	2.55	0.16	27.46	0.34	0.25	2.9	2.2
10-20	15	clay loam	6.23	1.16	2.00	0.12	13.19	0.15	0.11	2.6	1.9
20-30	25	clay loam	6.1	0.28	0.48	0.04	3.65	0.06	0.07	1.7	1.5
30-40	35	clay	6.03	0.18	0.31	0.04	3.01	0.05	0.03	1	0.9
B 0-10	B 5	clay loam	6.29	1.52	2.62	0.16	29.21	0.35	0.29	3.1	2.3
20-30	15	clay loam	6.25	1.29	2.22	0.14	19.05	0.23	0.2	2.9	2.1
20-30	25	clay loam	6.22	0.38	0.64	0.08	8.33	0.1	0.12	2.4	1.8
30-40	35	clay loam	6.12	0.16	0.28	0.04	5.88	0.07	0.08	1.9	1.2
C 0-10	C 5	clay loam	6.29	1.31	2.26	0.14	25.94	0.28	0.2	2.7	2
10-20	15	clay loam	6.26	1.08	1.86	0.11	11.38	0.12	0.1	2	1.4
20-30	25	clay loam	6.22	0.34	0.59	0.08	5.21	0.07	0.05	1.7	1.1
30-40	35	clay loam	6.43	0.29	0.50	0.04	4.71	0.04	0.03	0.9	0.7

Table 3
Consistency Limits of Experimental Soil

	Soil depth	MC %(db)	Liquid limit %	Plastic Limit	Plasticity index	Shrinkage limit
A	0-10	8.6	39.1	17.3	21.8	8.6
	10-20	9.3	40.2	18.4	21.8	9.3
	20-30	10.7	44.1	22.4	21.7	10.7
	30-40	10.0	43.0	21.4	21.6	10.0
B	0-10	9.3	41.9	22.1	19.8	9.3
	10-20	10.7	44.0	22.2	21.8	10.7
	20-30	10.0	42.1	20.2	21.9	10.0
	30-40	9.3	41.3	19.3	22.0	9.3
C	0-10	10.0	42.3	19.4	22.9	10.0
	10-20	11.4	45.2	20.3	24.9	11.4
	20-30	10.7	44.1	20.5	23.6	10.7
	30-40	10.0	42.2	21.4	20.8	10.0

As indicated in Table 2, the pH in water 1:2 is slightly acidic (6.03-6.43). The available P levels were relatively high and ranged from 3.01 to 29.21 mg/Kg being highest in the uppermost horizons (0-10 cm) as shown in Table 2. The amounts found in the three profiles showed that the P was exogenous in origin (fertilisers and organic matter mineralisation, Ortiz-Villajos *et al.*, 2011). The consistency limits of the experimental soils are shown in Table 3. The plasticity index of the three profiles A, B and C ranged from 8.6 to 10.7, 9.3 to 10.7 and 10.0 to 10.7, respectively.

The maximum shear strength of the experimental soil corresponding to 25 Proctor hammer (2.5 Kg) blows is given in Table 4. The range of the maximum shear strength was 150.75 to 156.14, 154.79 to 160.17 and 162.87 to 166.90 kPa for profiles A, B and C, respectively. This is quite low compared with 740.65, 620.56, 592.67 kPa for clay loam soil with organic matter content of 3, 10 and 17 %, respectively (Ohu *et al.*, 1986). The work of Nichols (1932) (Ohu *et al.*, 1986) reported maximum shear strength values in the range of 110 to 137.5 kPa for three clay soils at different moisture contents. This value agrees well with those obtained in this study. Similarly, maximum shear strength values 120 and 124 kPa for Piarco sandy loam and Talparo clay, respectively were reported (Ekwue & Stone, 1995).

The level of trace elements present in the profiles studied is presented in Table 5. The relatively low concentrations of trace elements in the experimental soils of the study area were mainly due to the fact that the area was largely rural with no industries. The levels of lead, zinc, iron, copper and chromium lie within the normal range of plant requirements specified by Brady and Weil (1996) and also within the safe limits proposed by the World Health Organisation (WHO) for total metal concentrations in soils (Tembo *et al.*, 2006; Rodriguez *et al.*, 2009). This implied that the utilisation of the soil for arable farming did not constitute any danger of micronutrient toxicity to crops or humans.

Table 4
Shear Strength of Compacted Soil

	Soil depth (cm)	Moisture content (%db)	Shear strength (kPa)
A	0-10	14.2	150.75 (3.09)*
	10-20	15.2	156.14 (2.56)
	20-30	15.1	154.79 (1.98)
	30-40	14.2	150.75 (2.09)
B	0-10	15.2	154.79 (3.09)
	10-20	15.1	156.14 (3.42)
	20-30	15.1	154.79 (2.98)
	30-40	16.2	160.17 (2.06)
C	0-10	16.3	162.87 (3.31)
	10-20	16.2	164.21 (2.78)
	20-30	17.1	166.90 (2.65)
	30-40	17.2	165.56 (3.02)

* Figures in parenthesis are standard deviation

Table 5
Trace Elements in Experimental Soil (mg/kg)

	Soil depth	Zn	Fe	Cr	Pb	Cu
A	0-10	0.33 (0.06)*	8.05 (1.09)	0.26 (0.03)	7.5 (0.63)	0.04(0.003)
	10-20	0.19 (0.04)	2.49 (0.42)	0.18 (0.02)	7.5 (0.54)	0.04 (0.002)
	20-30	0.14 (0.02)	2.78 (0.31)	0.11 (0.01)	7.4 (0.35)	0.04 (0.003)
	30-40	0.49 (0.07)	6.69 (0.35)	0.41 (0.01)	7.3 (0.51)	0.05 (0.001)
B	0-10	0.38 (0.03)	1.32 (0.06)	0.46 (0.02)	7.0 (0.35)	0.04 (0.002)
	10-20	0.72 (0.04)	1.60 (0.02)	0.13 (0.01)	8.5 (0.26)	0.05 (0.003)
	20-30	0.39 (0.05)	6.48 (0.92)	0.21(0.01)	7.0 (0.36)	0.06 (0.002)
	30-40	0.40 (0.03)	0.30 (0.07)	0.20 (0.02)	3.7 (0.25)	0.03 (0.003)
C	0-10	0.30 (0.01)	1.63 (0.5)	0.23 (0.02)	4.7 (0.21)	0.04 (0.002)
	10-20	0.17 (0.02)	5.15 (0.91)	0.14 (0.01)	3.3 (0.24)	0.04 (0.003)
	20-30	0.42 (0.01)	1.00 (0.10)	0.19 (0.01)	7.9 (0.19)	0.02 (0.001)
	30-40	0.69 (0.03)	1.24 (0.12)	0.35 (0.02)	5.9 (0.20)	0.04 (0.001)

*Figures in parenthesis are standard deviation

CONCLUSIONS

The following conclusions can be drawn from the study:

1. In general, the three profiles have similar characteristics with respect to their main geochemical and pedological properties. The most notable characteristics were the low organic matter content and the predominantly acidic pH.

2. The relatively low influence of human activity is indicated by the low concentrations of trace elements considered to be pollutants, namely Cu, Pb, Cr or Zn. The study data are potentially useful for evaluating potential uses of the soils in accordance with their content of trace elements.

3. The maximum shear strength value of the soils are in the range of 150 to 165 kPa.

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